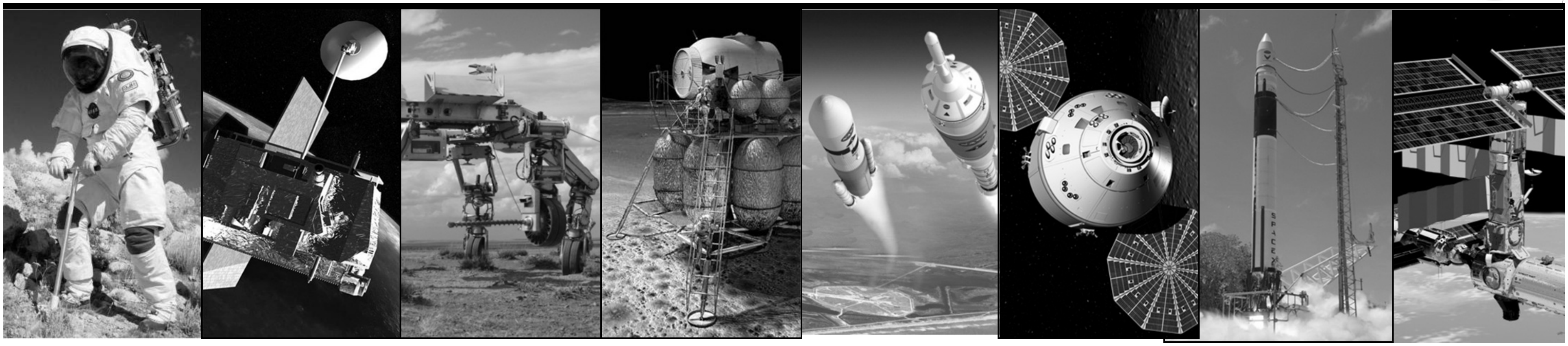
National Aeronautics and Space Administration



Supersonic Retropropulsion Flight Test Concepts

8th International Planetary Probe Workshop

Portsmouth, Virginia, 6-10 June 2011

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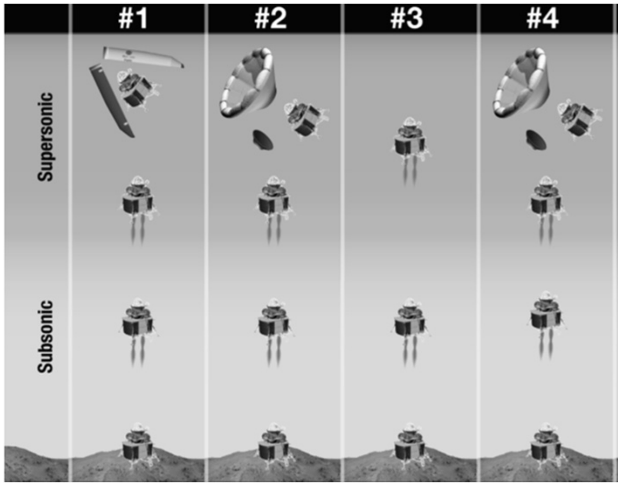
Introduction

- **Supersonic Retropropulsion (SRP):**
  - Initiation of a retropropulsion phase while the vehicle is traveling at supersonic conditions
  - Advanced entry, descent, and landing (EDL) decelerator technology
  - Potential enabler for high-mass (e.g. human-scale) missions to the surface of Mars
- NASA's Exploration Technology Development and Demonstration (ETDD) Project is investing in the maturation of SRP technologies
  - Computational Fluid Dynamics (CFD) analysis
  - Wind tunnel testing
  - Flight test concept development and systems analysis
  - Roadmapping to mature SRP from ~ TRL 2 to TRL 6
- Flight test concepts have been defined for a proof-of-concept flight test



Reference: NASA EDL-SA Phase 1 Report, NASA TM 2010-216720, 2010.

Reference: NASA ETDD LaRC UPWT FY 10 SRP Test

Objectives and Mission Requirements

Objectives

- Demonstrate *proof-of-concept* for SRP in a flight environment
- Replicate *relevant SRP physics* using a *minimally integrated system*
- Collect data during flight within acceptable uncertainties to satisfy relevant TRL achievement criteria
- Demonstrate the ability to design, package, integrate, and test SRP subsystems
- Reduce the risks associated with increasingly complex follow-on flight tests

Mission Requirements Summary

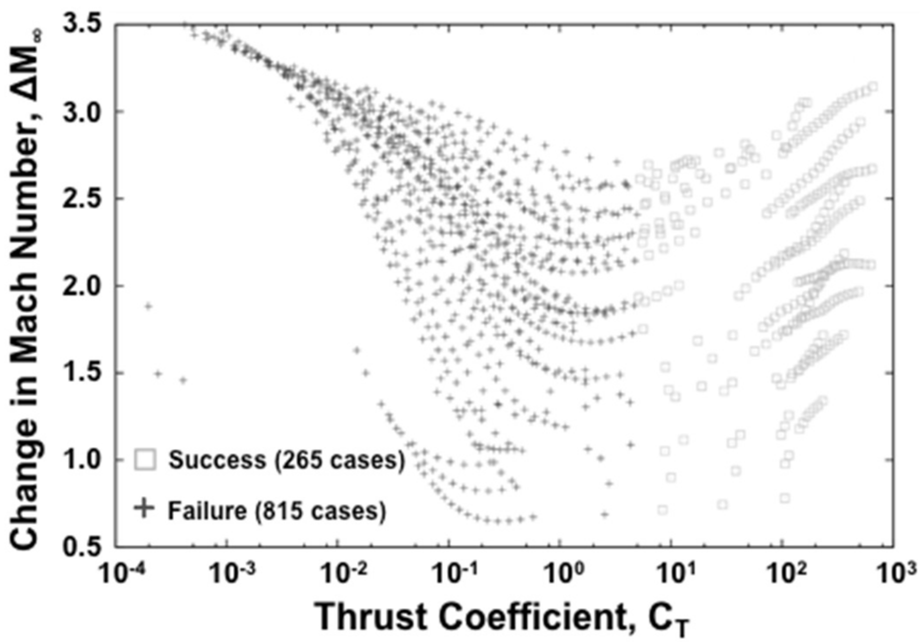
- Achievement of SRP (“hot”, propulsive jet flow against a supersonic freestream)
- Ballistic and stable flight throughout entire mission trajectory
- Utilization of existing components for launch system and test article
- Collection and analysis of data required for post-flight reconstruction, including:
  - Atmospheric characterization
  - 6-DOF vehicle state
  - Propulsion system performance and state
  - In-situ surface pressure and temperature

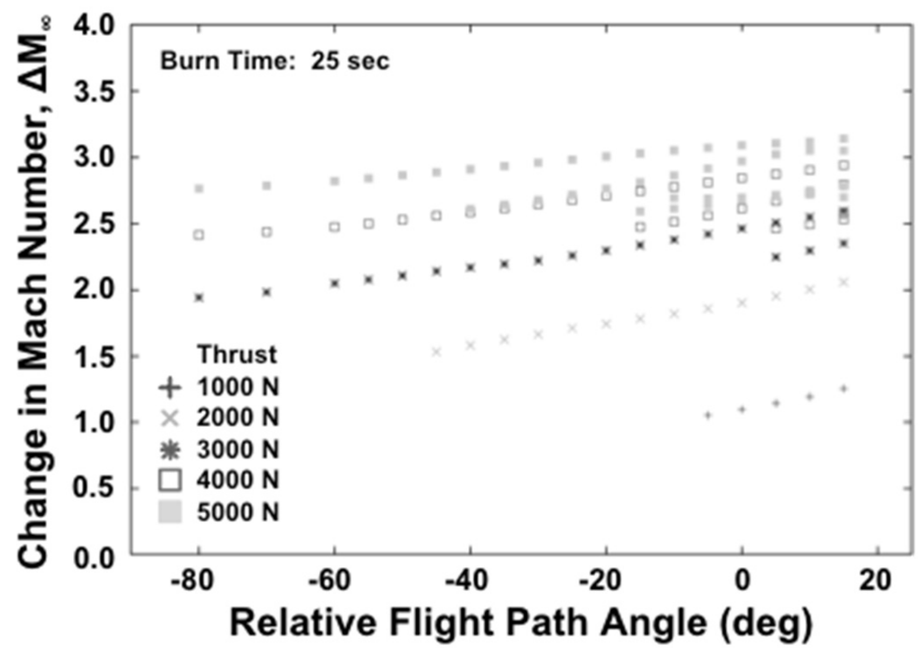
Test Phase Requirements

Duration	> 15 sec
M_∞ at initiation	> 2.0
C_T	> 5.0

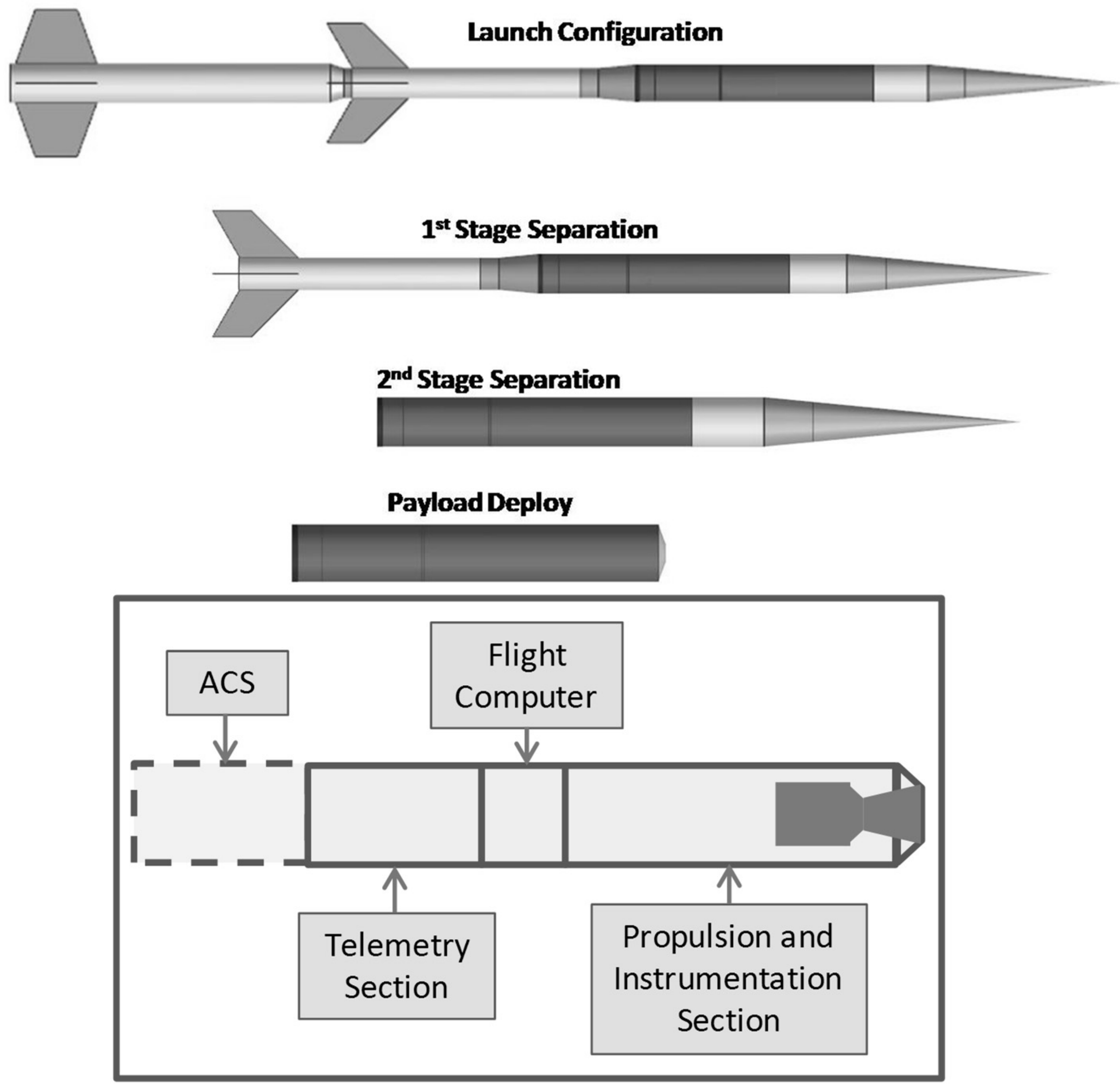
Initial Trade Study

- Objective:
  – Determine if a typical sounding rocket trajectory is a viable option for FT1
- Constraints:
  – $C_T > 5.0$
  – SRP initiation at Mach 3.5

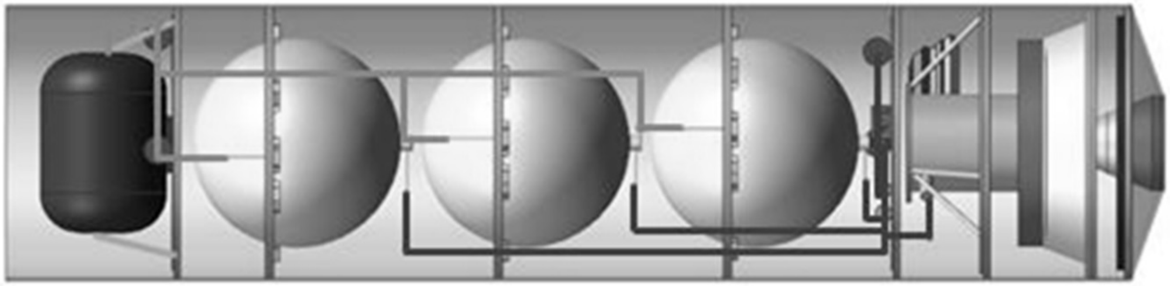




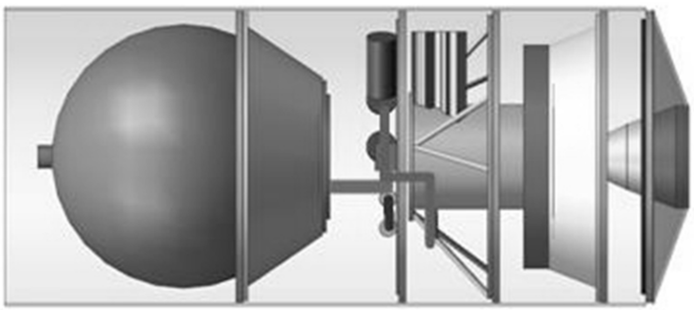
Generalized Flight Test Article



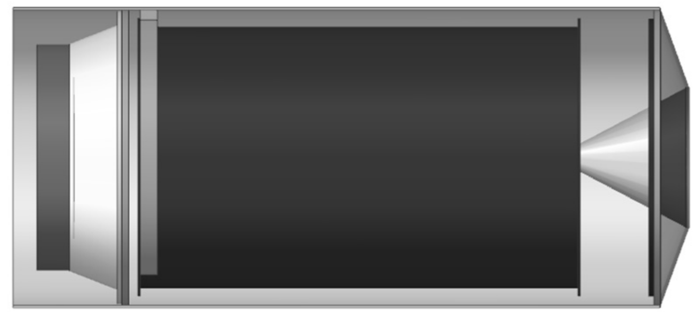
Concept Specific Packaging Study



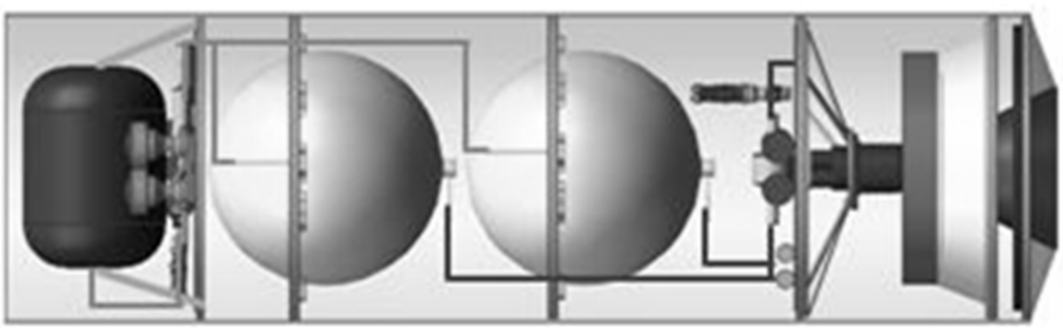
Pressure-Fed Monopropellant



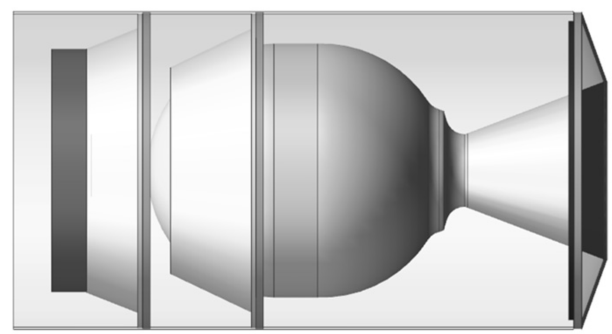
Blow-Down Monopropellant



STAR 15G SRM

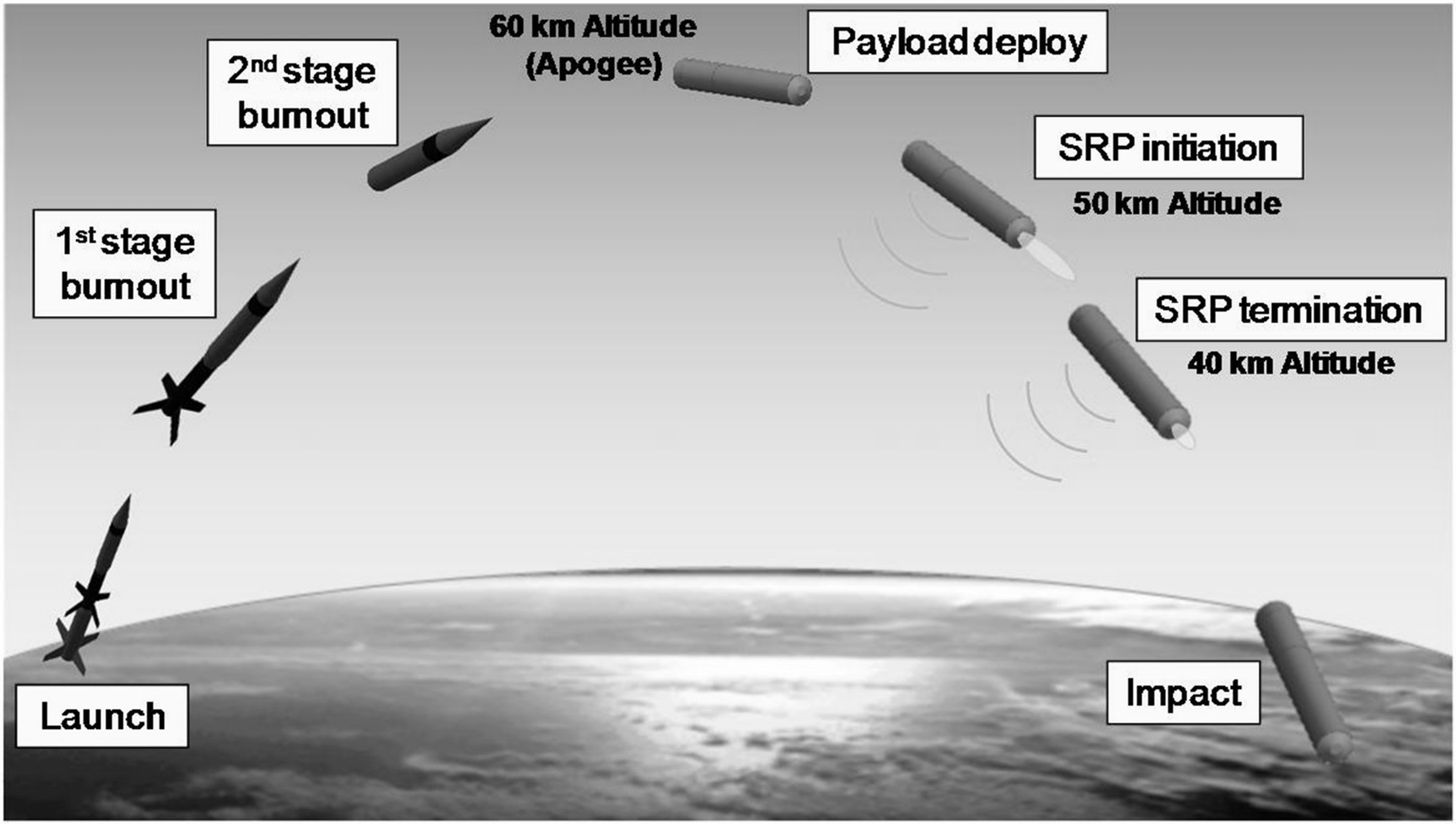


Pressure-Fed Bipropellant



STAR 13B SRM

Concept of Operations



Concept Specific Trade Study

- Objective:
  - Examine 5 FT 1 concepts using 3 different propellant types and explore the test space for each
- Trade Variables:
  - Propellant type
  - Packaging configuration
- Constraints:
  - $C_T > 5.0$
  - Post-shock stagnation pressure less than the nozzle exit static pressure ($p_{02} < p_e$)
- Trajectory based on Terrier-Improved Orion launch vehicle with test initiation at:
  - 50 km altitude
  - Flight path angle = -30.3°
  - Velocity = 871 m/s

Trade Study Results

Concept	Propellant Type	Burn Time (sec)	Thrust (N), max/min	$C_{T,min}$	$p_{02,max}$ / p_e (< 1.0)	ΔM_∞
1	N_2O_4 / MMH	30.0	4003 / 4003	8.0	0.680	0.85
2	Hydrazine (Pressure-fed)	35.0	3100 / 3100	4.2	1.170	0.40
3	Hydrazine (Blow-down)	24.0	3100 / 800	2.0	0.950	0.02
4	Solid (STAR 13B)	15.6	9643 / 6007	75.0	0.104	1.40
5	Solid (STAR 15G)	36.4	12460 / 1744	80.0	0.144	2.10

Status and Forward Work

- **Gathering information to focus the effort**
  - Options
    - Launch platforms
    - Test vehicle architectures
    - Propulsion systems
  - Performance criteria include C_T, range of Mach number
    - Small perceived benefit to test initiation at $M_\infty > 2$
    - Deceleration through the transonic regime viewed as strongly beneficial

- **View of test as proof-of-concept allows for de-emphasis on some performance differences between architectures, providing that:**
  - Test phase is initiated at supersonic conditions
  - $C_T > 5$ is maintained over majority of test phase

- **Evaluating important cost factors**
  - Sounding rocket costs less than Viking BLDT type platform
  - Determine costs of actively controlled vs. passively stabilized test vehicle
  - Compare hard costs and schedule costs of viable test vehicle engine options
    - Long lead time (years) and other availability issues with some motors
    - Opportunities to obtain left-over RCS engines from Space Shuttle
    - Opportunities to use industrial grade engines/tanks
    - Opportunities to partner with engine developers (LOX/CH_4)

Summary

- Sounding rocket identified as a viable platform for a proof of concept flight test of SRP
  - Identified a large range of trajectories capable of satisfying test phase requirements
- Five flight test concepts were considered
  - Demonstrated ability to package concepts on a sounding rocket
  - Additional cost information to be gathered for each concept
- Identified two Concept of Operations that satisfy test phase requirements
  - Trajectories and ConOps will be optimized following down-selection of flight test concepts

Acknowledgements

The authors would like to acknowledge the support of the Exploration Technology Development and Demonstration (ETDD) Program, managed at NASA-Glenn Research Center. The work documented herein was performed as part of ETDD's Entry, Descent, and Landing (EDL) Technology Development Project, which is managed at NASA-Langley Research Center and supported by NASA-Ames Research Center, NASA-Johnson Space Center, and the Jet Propulsion Laboratory.

We would also like to acknowledge Art Casillas, Jeremy Shidner, Bill Studak and Wallops Flight Facility for their analysis support and guidance.